ILRI publication 43

BASCAD

A mathematical model for level basin irrigation

J.Boonstra
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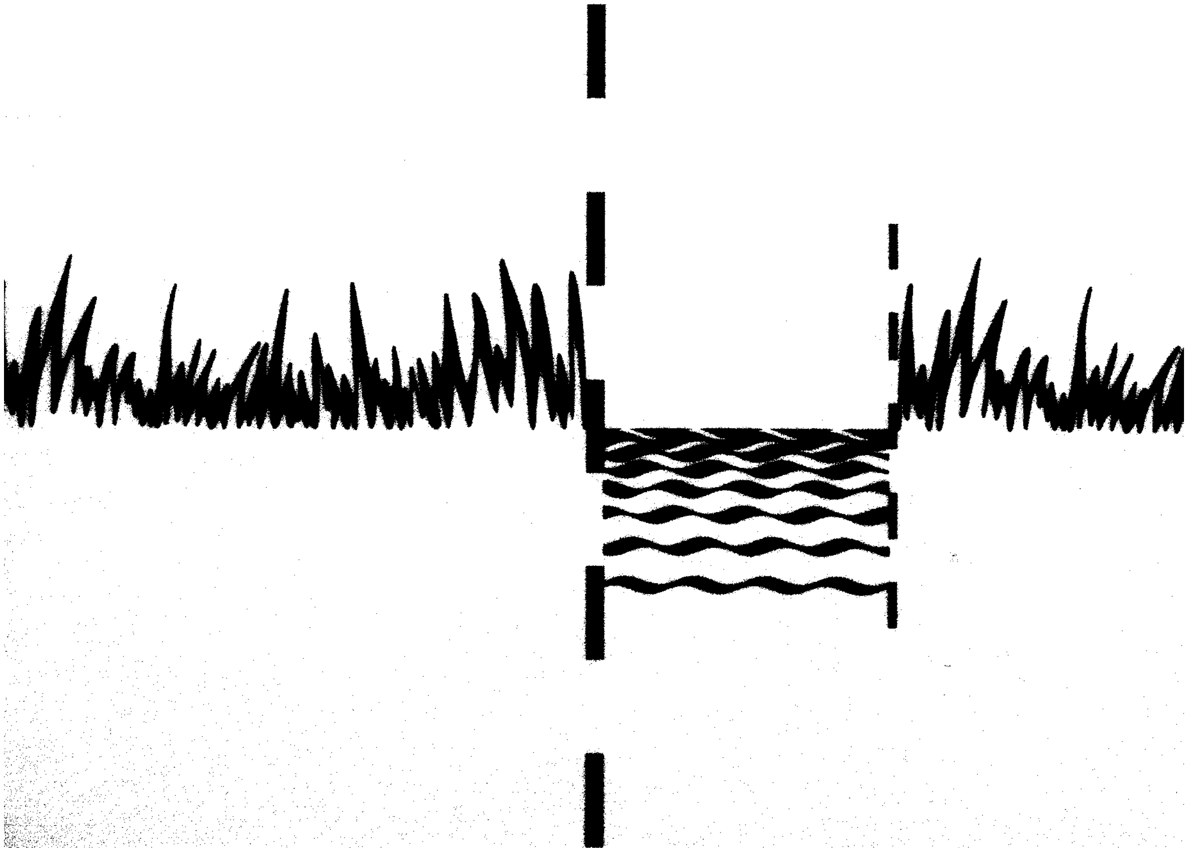

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International Institute for Land Reclamation and Improvement/ILRI
P.O.Box 45, 6700 AA Wageningen, The Netherlands 1988.

ISBN 90 70754 12 6

Printed in the Netherlands.

Preface

The need for better water management in surface-irrigation systems is clearly shown by their usually low water-application efficiencies – typically less than 60 per cent. Nevertheless, surface systems, when properly designed and managed, can attain much higher application efficiencies. The purpose of surface-irrigation models is to improve the design and management of these systems.

With this in mind, we wrote BASCAD (BAS = Basin, CAD = Computer-Aided Design), a mathematical model for basin irrigation. BASCAD is the result of many years of work. The nucleus was developed in 1984 in collaboration with Suzanne Geldof of IWIS/TNO in The Hague. Since then, we have added to it step by step. Various colleagues have made trial runs with different versions of the BASCAD program, which we have modified in response to their comments and suggestions.

A copy of the compiled version of the program, written in BASIC, is included with this manual. It comes on a $5^1/_4$-inch floppy disc in MS-DOS format, and will run on any IBM-compatible microcomputer. As a service to users, a FORTRAN version of the program is also available. It comes on a 9-track magnetic tape in ASCII format. Requests for the FORTRAN version should be addressed to the International Institute for Land Reclamation and Improvement in Wageningen, The Netherlands.

The Authors

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Small basins (100 m^2 each)
(Courtesy, M.G.Bos, ILRI)

1 Introduction

Basin irrigation is the most widespread method of surface irrigation. In developing countries, it is more common than sprinkler and drip irrigation and the other methods of surface irrigation: furrows and borders. In the U.S.A. and Australia, basin irrigation is experiencing a revival thanks to the very good land preparation that is possible with laser levelling. Large basins can now be irrigated with a high efficiency and a low labor requirement.

Irrigating large basins is not practical under the conditions that are common in developing countries. Nevertheless, basins in these countries can certainly be made bigger than their present, very small size.

Sound design and management will improve the performance of field irrigation. To realize this improvement, however, requires a good insight into the complex behaviour and interrelations of many parameters.

BASCAD will provide that insight. BASCAD is a mathematical model for basin irrigation (BAS = Basin, CAD = Computer-Aided Design). With it, the user can design level basins to match the local management parameters. In addition, the user can analyze the actual performance of a given irrigation application in a basin of known size.

Large basin (4 ha)
(Courtesy, A.R.Dedrick, U.S. Water Conservation Laboratory, Phoenix, AZ)

2 General description of basin irrigation

A level basin is defined as a level field surrounded by bunds and having no surface runoff. The field is irrigated with a flow rate high enough to keep the difference between the infiltration opportunity times for the upstream and downstream end of the basin small in comparison with the time needed to infiltrate the required depth. The most infiltration occurs while there is a layer of standing water on the field. Consequently, infiltration in the field is fairly uniform and the application efficiency is high.

In basin irrigation, we can differentiate three phases:

- The advance phase. Water is let into the basin, where it flows towards the opposite end. Due to infiltration, part of the flow is lost as it goes along. The more infiltration there is in the upstream end of the basin, the longer it will take the water to reach the downstream end. If the flow rate is high enough compared with the infiltration capacity of the soil, the water will reach the downstream end of the basin and be stored on the surface before all of it infiltrates;
- The ponding phase. Once the water reaches the downstream end of the basin and the inflow continues, surface storage will increase and a uniform water layer will gradually form;
- The depletion phase. After the inflow has ceased, the ponded water will infiltrate until it finally disappears. Because the water layer remains even, it is commonly assumed that the water disappears at the same moment all over the basin.

Note that in specific situations, for instance in large basins with high flow rates, reality differs from the description above. In these situations, the inflow ceases before water has reached the downstream end and no ponding phase occurs.

Basin irrigation involves several parameters, i.e. the flow rate, the application time, the infiltration characteristics of the soil, the resistance to overland flow, and the basin dimensions. A specific combination of these parameters determines the pattern of the infiltrated depths over the basin.

The performance of a field application method is assessed by comparing the actual infiltrated depths with the required uniform depth of water.

When a constant flow is applied to a basin with a uniform infiltration rate and uniform flow resistance characteristics, infiltration will be at a maximum at the upstream end (D_{max}) and decrease gradually to a minimum at the downstream end (D_{min}). One of two situations can then arise:

1. The minimum infiltrated depth is equal to or more than the required depth (Figure 1). Over-irrigation occurs over the whole length of the basin and the results can be expressed in terms of the application efficiency (E_a). The application efficiency is defined as the ratio of the required depth (D_{req}) to the average applied depth (D_{av}). This definition corresponds with the ICID definition (Bos 1984). In level basins, without surface runoff, the average depth applied to the field equals the average infiltrated depth.
2. The minimum infiltrated depth is less than the required depth (Figure 2). In this case there is over-irrigation on the upstream part of the basin and under-irrigation

on the downstream part.

Because the application efficiency is now no longer a sufficient parameter, we have added another, i.e. the storage efficiency (E_s), which is the ratio of the average depth of water (D_s) actually stored in a soil layer that can store the required depth, and the required depth (D_{req}) itself (Israelsen and Hansen 1962; see also Hart et al 1979).

When the average applied depth is less than the required depth ($D_{av} < D_{req}$), the application efficiency according to the definition $E_a = D_{req} / D_{av}$ will be more than 100 per cent. Because this is in conflict with the idea of efficiency, it is better to say that in such situations the application efficiency is no longer valid as a performance parameter.

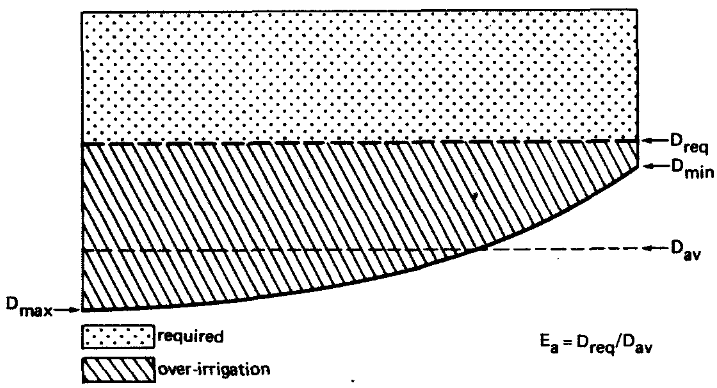


Figure 1. The minimum infiltrated depth is more than the required depth, resulting in over-irrigation over the whole basin

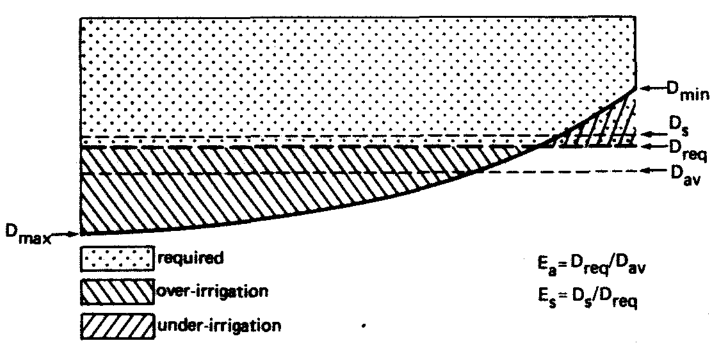


Figure 2. The minimum infiltrated depth is less than the required depth, resulting in over-irrigation in the upstream part of the basin and under-irrigation in the downstream part

Finally, one must be careful with the concept 'infiltrated depths'. Infiltration refers to volumes of water, which can also be expressed as depths of imaginary, uniform water layers. These depths should not be regarded as the actual depths to which the water penetrates the soil, as the actual depths depend on the initial soil moisture content before irrigation and the soil's moisture holding properties.

3 Program features

The partial differential equations that govern surface flow are known as the Saint-Venant equations. They consist of an equation of continuity (mass conservation) and an equation of motion. Katopodes and Strelkoff (1977) showed for border irrigation that when Froude numbers are sufficiently low, they can be assumed to be zero with essentially no loss of accuracy. This has the same effect as the assumption that accelerations are negligible, which Strelkoff and Katopodes (1977) postulated in their zero-inertia approach to border irrigation.

BASCAD is based on this zero-inertia approach to solving the Saint-Venant equations. Analysis of the flow in the surface stream begins by dividing the basin length into a number of equal sections. The profile of depth and discharge in the surface stream is computed by satisfying the conservation of mass and equilibrium of forces in each section. The conservation of mass includes both the water stored at the surface and the water absorbed into the soil.

During the advance of water across the basin length, the sections are filled, one after another, in increasing time steps. Except for the lead section, each profile in a section is based on the results of the preceding time step in that section. The partial differential equations are therefore discretized in space and time with an implicit finite difference scheme. This procedure yields sets of algebraic non-linear equations, which are solved in BASCAD by the Newton-Raphson iterative method.

In this way, the profile in the surface stream gradually lengthens until the stream front reaches the downstream end of the basin. Two situations can now occur:

1. If the infiltration at the downstream end of the basin is specified, BASCAD will calculate the time required for it to occur. Based on this time and the infiltrated depths at the end of the advance, the required application time and final infiltration profile are determined.
2. If the application time is specified, BASCAD will calculate the additional infiltration that will take place after the advance has ceased. The final infiltration profile is then determined.

In both situations, it is assumed that during the recession the ponded water layer remains horizontal and the water disappears at the same moment all over the basin.

BASCAD operates under the following assumptions:

- the inflow is constant during the application time;
- the water is applied evenly to the upstream end of the basin;
- the basin is bounded by bunds so that no surface runoff occurs;
- the slope of the basin is zero in all directions (level basin);
- the flow resistance and infiltration characteristics are constant over the basin;
- the program cannot handle situations where the application time is considerably less than the advance time.

With regard to the last restriction, the algorithm used in the BASCAD program cannot analyze situations where flow continues under its own gradient after inflow has stopped. This means that BASCAD cannot calculate situations where the application

Inflow is evenly distributed over the basin width
(Courtesy, M.G.Bos, ILRI)

time is less than the advance time. When this occurs, but the application time is greater than the advance time at 90 per cent of the basin length, BASCAD will still give the output parameters. They will be theoretically wrong, but accurate enough for practical purposes.
When the application time is less than the advance time at 90 per cent of the basin length, the program will break off and flash a message on the screen (see Chapter 7). This is a signal that the errors in the results can no longer be ignored or that flow will never reach the downstream end, which is in conflict with our concept of designing level basins.

The user can run the program in four different modes (Table 1). In the first three modes, the calculated minimum infiltration at the downstream end of the basin (D_{min}) is equal to the required depth (D_{req}).

Table 1. Relevant characteristics of the four modes of BASCAD[1)]

Mode	Input	Output	Remarks
1	Q	L, B, T_s, E_a	$D_{min} = D_{req}$, $E_s = 100\%$
2	L, B	Q, T_s, E_a	$D_{min} = D_{req}$, $E_s = 100\%$
3	Q, L, B	T_s, E_a	$D_{min} = D_{req}$, $E_s = 100\%$
4	Q, L, B, T_s	E_a, E_s	

[1)] See List of Symbols for explanation

Mode 1
The user enters the inflow rate (Q) and the required depth (D_{req}). The program will calculate the basin dimensions (L and B) and the required application time (T_s). These output parameters are determined in such a way that the corresponding application efficiency (E_a) will exceed 60 per cent.

Mode 2
The user enters the basin dimensions and the required depth. The program will calculate the required inflow rate and the application time, yielding application efficiencies similar to those in Mode 1.

Mode 3
The user enters the inflow rate and the required depth for a basin of known size. The program will calculate the required application time and the resulting application efficiency.

Mode 4
The user enters the inflow rate and the application time for a basin of known size. The program will calculate the minimum infiltrated depth at the basin's downstream end. Depending on the specified required depth, the amount of over-irrigation and/or under-irrigation, the application efficiency (E_a), and the storage efficiency (E_s) are calculated.

BASCAD will give the user an acceptable result in Modes 1 or 2 and will indicate the consequences of changing one or more of the design parameters in Modes 3 and/or 4.

4 Running the program

Load the micro-computer with the appropriate operating system and initialize the program by typing BASCAD and pressing the carriage return key. This key will be marked with either an angle arrow, the word ENTER, or the word RETURN. From here on, this key will be referred to as the ENTER key.

Use the keyboard to enter input. During the interactive session, the program will ask two different types of questions:

1. Questions that require a yes or no answer. These are followed by (Y/N)? or (N/Y)?. If the question ends with (Y/N)? and the answer is yes, type Y (or y) and press the ENTER key, or simply press the ENTER key. If the question ends with (N/Y)? and the answer is no, type N (or n) and press the ENTER key, or simply press the ENTER key;
2. Questions about the displayed values of the input data. These are followed by a question mark only. If the value displayed is correct, simply press the ENTER key. If not, type in the correct value after the question mark and then press the ENTER key.

The above conventions keep to a minimum the steps that you must complete.

When BASCAD is run for the first time in a session, it will display a set of standard input parameters whose values can be changed from the keybord. If it is rerun, either in the same or another mode, it will always display the most recent set of input parameters. These parameters can be changed again if so desired.

BASCAD always displays the results of any calculations. While BASCAD gives you the option of printing out the input and output parameters, you do not need a line printer to run the program.

To exit from the program, type N and press the ENTER key when the question 'WOULD YOU LIKE TO MAKE ANOTHER ANALYSIS (Y/N)?' is displayed on the screen. This is the regular way to exit from BASCAD. To stop the program at any time during the calculations, press the CTRL (control) and BREAK keys simultaneously. Do this only if you have made a mistake in entering the input data and are running Modes 1 or 2.

5 Input parameters

BASCAD accepts values for input parameters within certain ranges (Table 2). These input parameters are discussed below.

Number of sections
To simulate the propagation of water over the basin surface, the basin length is split up into a number of sections in all of the program modes. In general, the more sections that are chosen, the more accurate the results of the computations will be, but the more time those computations will take. For the sake of practicality, there is a trade-off between accuracy and computation time.
A value of ten sections has been found to work satisfactorily in most cases. In Modes 1 and 2, the program makes the calculations with this value. In Modes 3 and 4, the user has the option of changing the number of sections. In Mode 4, a value of 20 or more sections will occasionally be required.

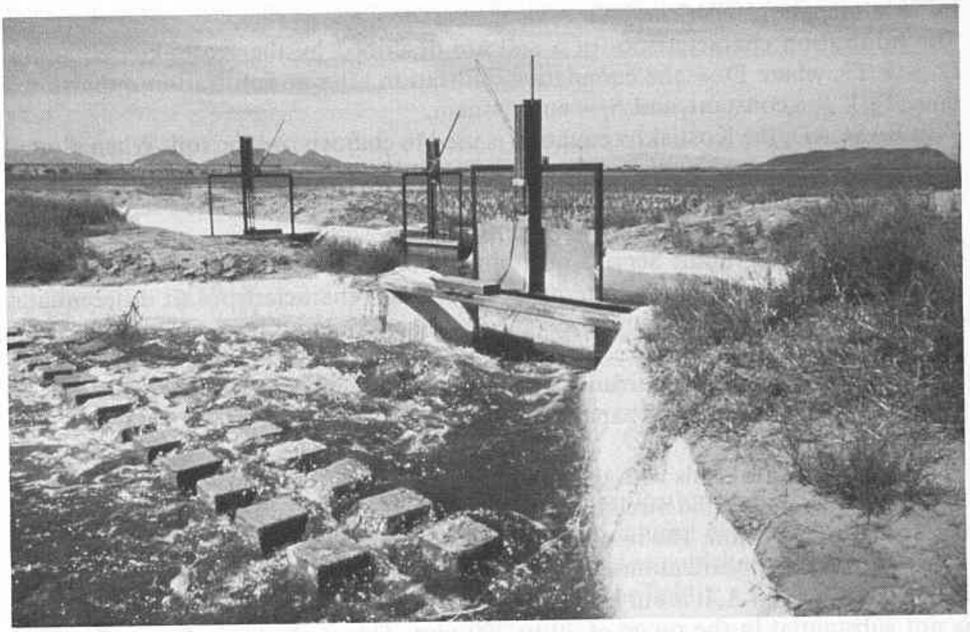
Constant inflow rate (Q)
The inflow rate is the available flow size; in Modes 1, 3, and 4, it must be specified (litres per second). Although BASCAD assumes that the inflow is evenly applied over the upstream width of the basin, it will give acceptable results for basins with a point inlet as well.

Table 2. Overview of input parameters and ranges

Input parameters	Modes 1	2	3	4	Range of accepted values
Number of sections			•	•	5–30
Constant inflow rate	•		•	•	5–600 l/s
Application time				•	10–800 min
Required depth	•	•	•	•	40–500 mm
Maximum length-width ratio	•				1–5
Basin length		•	•	•	5–800 m
Basin width		•	•	•	5–500 m
Flow resistance	•	•	•	•	.01– .50
Infiltration parameter A	•	•	•	•	0.2–1.0
Infiltration parameter k	•	•	•	•	0.05–2.50 mm/s[A]

Application time (T_s)
The application time is the period during which a certain constant inflow rate is applied to the basin. In Mode 4, the application time must be specified (minutes).

Required depth (D_{req})
The required depth is the depth of water to be applied to the soil, expressed in millimetres of an imaginary water layer. It is usually determined on the basis of the root



Concentrated inflow
(Courtesy, A.R.Dedrick, U.S. Water Conservation Laboratory, Phoenix, AZ)

zone depth of a crop, the field capacity and wilting point of the soil, and a percentage of readily available moisture, depending on the crop and the evapotranspiration. In Modes 1, 2, and 3, the required depth is realized at the end of the basin. This will not usually be the case in Mode 4.

Maximum length-width ratio (L/B)
In Mode 1, the maximum length-width ratio can be specified by the user. The program then calculates the length and width of the basin.

Basin length (L) and width (B)
In Modes 2, 3, and 4 the length and width of the basin must be specified (metres).

Flow resistance (n)
In all Modes, the Manning equation is used to calculate the flow over the soil surface. In this formula, the flow resistance (or roughness) is an important factor. It expresses the resistance effects on the flow of the hydraulic boundary conditions. Soil surface conditions, cultivation practices, and types of crops result in a certain flow resistance. According to the Soil Conservation Service (USDA 1974), the following values may be used:

n = 0.04 for smooth, bare soils; row crops (parallel to flow direction);
n = 0.10 for drilled small-grain crops (parallel to flow direction);
n = 0.15 for alfalfa; mint; broadcast small-grain crops;
n = 0.25 for dense sod crops; drilled small-grain crops (perpendicular to flow direction).

Infiltration parameters (k and A).
The infiltration characteristics of a soil are described by the Kostiakov equation: $D = k\ T^A$, where D = the cumulative infiltration after an infiltration opportunity time (T), k = a constant, and A = an exponent.

In BASCAD, the Kostiakov equation is used to characterize the soil. When plotted on log-log paper, the equation produces a straight line (Figure 3). The k value in this equation corresponds with the value of D at T = 1, and the A value represents the tangent of the straight line.

The Soil Conservation Service, in its handbook for designing border irrigation (USDA 1974), classifies soils in terms of infiltration characteristics. It differentiates eight 'intake families', which are assigned numbers ranging from 0.1 to 4.0. These numbers represent the nearly constant intake rate, in inches per hour, that develops after a sufficiently long opportunity time. The S.C.S. intake families produce curved lines when plotted on log-log paper (Figure 3).

To describe identical soils with the Kostiakov equation, these curved lines should be linearized. Fangmeier and Strelkoff (1979) made such a linearization based on infiltrations of 50 and 100 mm. The resulting values for k and A are given in Table 3.

Although other linearizations (for instance between 60 and 120 mm) will yield different values for k and A, it is our experience that the influence of different linearizations is not substantial in the range of 30 to 200 mm. This is shown in Figure 3, where the S.C.S intake family of 1 inch per hour has been plotted along with its linearized equivalent based on the Kostiakov equation.

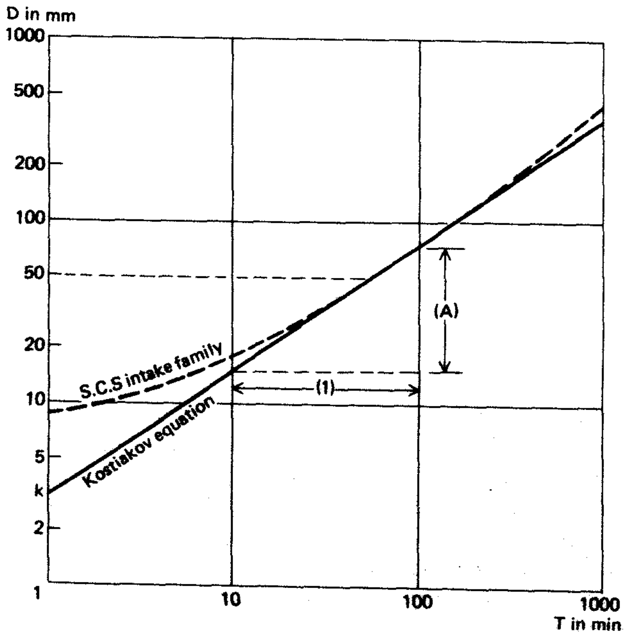


Figure 3. Graph of different infiltration equations

Table 3. Transformation of SCS intake families into Kostiakov parameters (using depth limits of 50 and 100 mm) and corresponding soil classes

Intake families S.C.S. (inches/h)	Kostiakov equation k (mm/s^A)	A (–)	Soil classes
0.1	0.096	0.595	clay, silty clay
0.3	0.111	0.650	silty clay, clay loam
0.5	0.117	0.684	clay loam, loam
1.0	0.158	0.706	loam, silt loam
1.5	0.188	0.718	silt, sandy loam
2.0	0.216	0.726	sandy loam, fine sand
3.0	0.267	0.735	fine to medium sand
4.0	0.314	0.740	medium to coarse sand

For various reasons, it is difficult to base soil classifications solely on the S.C.S. infiltration families. The soil classes given in the last column of Table 3 are averages of data found throughout the literature and can be used as guidelines. We recommend, however, determining the soil constants (k and A) in the field, e.g. with a ring infiltrometer.

The soil constant (k) should be prescribed in millimetres per second^A ($k = D/T^A$); the soil constant (A) is dimensionless.

6 Output parameters

After the input data have been entered, the results of the calculations will appear on the screen. Table 4 gives an overview of the output parameters for all four modes. These parameters and their interpretations will be discussed below in more detail.

Infiltration

In Modes 1, 2, and 3, the program will automatically make the minimum infiltrated depth at the end of the basin equal to the required depth. Because irrigation water can never infiltrate uniformly over the whole basin, more water will infiltrate over the length of the basin than is required. To indicate the magnitude of this phenomenon, the program also shows the maximum infiltrated depth and the average applied depth (both in mm) and the application efficiency (%).

Over/under-irrigation

In Mode 4, the application time is specified. This results in a certain minimum infiltrated depth at the end of the basin. Usually this minimum depth differs from the required depth. Figure 2 shows a situation where the required depth is somewhere between the maximum and minimum infiltrated depths.

Table 4. Overview of output parameters

Output parameters	Modes			
	1	2	3	4
Basin length	•			
Basin width	•			
Constant inflow rate		•		
Minimum infiltration				•
Maximum infiltration	•	•	•	•
Average applied depth	•	•	•	•
Over-irrigation				•
Under-irrigation				•
Application efficiency	•	•	•	•
Storage efficiency				•
Application time	•	•	•	
Advance time	•	•	•	•
Recession time	•	•	•	•

Over-irrigation is expressed as the average depth (mm) in that part of the basin (m) where excess infiltration occurs. In the rest of the basin, the infiltrated depth is less then the required depth. This shortage is expressed as the average depth (mm) in that part of the basin (m) where insufficient infiltration occurs, and is called under-irrigation. It must be noted that the over and under-irrigation, although expressed in millimetres, cannot be compared with the average applied depth because different lengths within the basin are used to convert volumes into depths.

The storage efficiency is given as a measurement of under-irrigation. If the average applied depth is less than the required depth, a message will appear on the screen. The application efficiency is then no longer given (see Chapter 2).

Advance/recession time

In all the modes, the advance time (min) is given. The advance time is how long it takes the water to travel to the downstream end of the basin from the start of the irrigation. When the water reaches the end of the basin, ponding will begin. After cut-off of the inflow, the water stored on the surface will decline. The time it takes the water to disappear from the surface after the start of the irrigation is called the recession time (min).

The other output parameters listed in Table 4 are input parameters in one or more modes. They were discussed in Chapter 5.

7 Program diagnostics

BASCAD will usually produce an output as a result of the calculations. Yet, in a number of cases, the user will be confronted with the following screen message:

Change one or more input parameters

To aid the user in such a situation, that message is followed by suggestions as to how he can still get a result. There are basically two problems that will lead to such a program break: one of scaling and one of application time.

Scaling problem

According to the calculation algorithm used in BASCAD, the parameters must be scaled, which can never be done so that all the possible combinations of all the input parameters can always be solved. A problem will occur if there is an imbalance between the input parameters. For instance, if there is a very small inflow rate, a very large basin, or a combination of the two. Because in Modes 1 and 2 only one of the two parameters can be specified, the user will have no problem. Difficulties due to an imbalance can arise, however, in Modes 3 and 4.

When running the program in Mode 3, the user should either increase the constant inflow rate or decrease the basin dimensions. The user can also try increasing the number of sections. Nevertheless, it is our experience that if this yields any output parameters at all, the application efficiency of the irrigation will be poor.

In Mode 4, the user will have to increase the number of sections to evaluate the design of an existing basin. Note that increasing the number of sections to over twenty will drastically lengthen the required computation time. For that reason, we have limited the number of sections to a maximum of thirty.

Application time problem

BASCAD cannot handle situations where the calculated or specified application time is substantially less than the calculated advance time (see Chapter 3). This shorter application time can be due to several factors. For instance, a high inflow rate or a short basin will give a low advance time, but to achieve a certain minimum depth, these parameters can give an even lower application time. The same phenomenon occurs if the specified application time is too short. To make it very short can mean that the water will not even reach the downstream end of the basin. Consequently, no one single cause or remedy can be generally indicated. The following suggestions have been incorporated into the program and will appear on the screen if a program break occurs:

- In Mode 1, the constant inflow rate should be decreased. This will cause a relatively greater increase in the application time than in the advance time. The basin length cannot be changed because in this Mode it is an output parameter;
- In Mode 2, the basin length should be decreased. This will cause a relatively greater decrease in the advance time than in the application time. The inflow rate cannot

be changed because in this Mode it is an output parameter;
- In Mode 3, the inflow rate and/or the basin length should be decreased. This will have the same effects described above for Modes 1 and 2;
- In Mode 4, the suggestions made for Mode 3 still apply. A quite different situation can occur, however, i.e. a too-short specified application time. In such a case, the user should either increase (instead of decrease, as in Modes 1 and 3)) the inflow rate, increase the application time, or decrease the basin length.
  An increase in the inflow rate will cause a decrease in the advance time, while not affecting the application time. A decrease in the basin length will cause a greater decrease in the advance time than in the application time.

The suggestions displayed on the screen are based on the problems met in the calculations and on the particular mode in which the program is running. After they have been displayed, the last set of input parameters will be displayed. The user is then free to follow any of the suggestions and change one or more of the input parameters.

8 Guidelines

In level basin irrigation, there are two basic types of problems:
- A certain minimum infiltrated depth must be achieved and a certain minimum application efficiency realized. If the basin dimensions are known, the required flow size must be determined. If the flow size is known, the basin dimensions must be determined. In both cases, the application time must be determined;
- If the application time, flow size, and basin dimensions are all known, the minimum infiltrated depth must be determined along with the resulting performance in terms of under-irrigation and/or over-irrigation.

The first type of problem is a typical design question: how to achieve a certain result? This question can be answered with Mode 3 of the program. It might, however, be difficult for less experienced users to find an appropriate combination of input parameters with this Mode, and a repetition of messages could result. To facilitate the work, the user can run Mode 1 to get a first estimate of the basin dimensions or Mode 2 to get a first estimate of the flow size. Mode 3 can be used subsequently to make further refinements.

The second type of problem concerns the analysis of an existing situation. This problem can be solved with Mode 4.

The flow diagram in Figure 4 shows how the Modes can be run in different sequences. Note that because BASCAD has no fixed running sequence, the diagram is meant only as a guideline.

The following were considered when developing the flow diagram:
- In Modes 1, 2, and 3, the calculated minimum infiltrated depth at the end of the basin will always be equal to the required depth. This implies that the storage efficiency will always be 100 per cent. For design purposes, therefore, we advise starting BASCAD in either Mode 1, 2, or 3;
- The main advantage of Modes 1 and 2 is that when either the inflow rate (Mode 1) or the basin dimensions (Mode 2) is specified, the program will present an acceptable solution with respect to the irrigation performance. A secondary advantage is that the user is seldom confronted with program diagnostics. Nevertheless, these Modes take more time to run than Modes 3 and 4. Therefore we advise running them only once and then continuing with Modes 3 or 4, repeatedly if necessary;
- Mode 3 is very suitable for establishing the consequences of changing one or more of the input parameters. A disadvantage of starting BASCAD in Mode 3 is that the user might select values of inflow rate and basin dimensions that either will lead to inacceptable irrigation performances or repeated program diagnostics;
- Mode 4 has the same advantages and disadvantages as Mode 3. Mode 4 is very suitable for analyzing the irrigation performance in an existing situation. For evaluation purposes, therefore, we advise starting the program in this Mode.

Whether the results of a certain run are acceptable or not can be decided from two types of criteria. The first has to do with the irrigation performance as indicated by

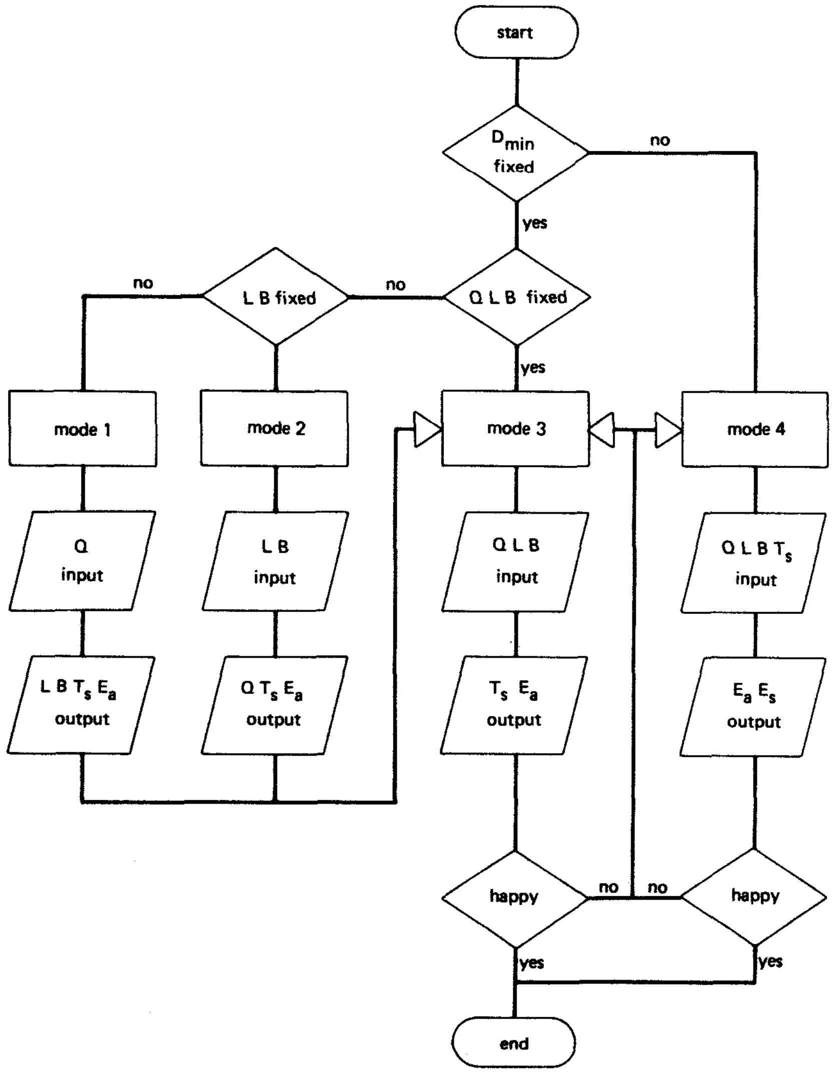


Figure 4. Suggested running sequences for BASCAD (the input parameters n, k, A, and D_{req} are not shown)

the infiltrated depths and the related over and/or under-irrigation. The second has to do with the irrigation system design and management in a broader sense. Here, one also has to include the lay-out of the tertiary unit (related to farm dimensions), the topography (basin dimensions that are possible with respect to levelling), water distribution in the tertiary unit (available flow size and application time for individual farms), acceptable flow sizes to be handled by a farmer, and so on.

Thus it is possible that the total set of results from a certain run will meet the first type of criteria, but not the second, or vice versa. Making further changes in one or more of the parameters and rerunning BASCAD in the same or another mode will finally yield a solution that will meet both types of criteria.

9 Sample problems

As mentioned in Chapter 8, there is no set procedure for using BASCAD. We have therefore included two sample problems. Note that no fixed design procedures can be derived from these examples. The sequence in which the Modes are run is hypothetical.

Problem 1

Given:
The infiltration capacity of a soil is characterized by $k = 0.14$ and $A = 0.72$, and the flow resistance of the basin is $n = 0.20$.

The required depth of infiltration is $D_{req} = 100$ mm and the available flow rate is $Q = 30$ l/s.

Question:
What should be the basin dimensions (L and B) if the maximum ratio of length over width $L/B \leqq 2$?

Solution:
Start in Mode 1. The input and output parameters of this run are presented in Column 2 of Table 5.

Suppose that the calculated basin length and width ($L = 57$ m and $B = 28$ m) are not satisfactory. Continue by running Mode 3 and specify, for instance, $L = 60$ m and $B = 40$ m. The input and output parameters of this run are presented in Column 3 of Table 5.

Suppose we want to increase the application efficiency ($E_a = 74\%$). One remedy is to make the basin shorter. Rerun Mode 3, taking $L = 50$ m and $B = 40$ m. The input and output parameters of this run are presented in Column 4 of Table 5.

Suppose that these results are acceptable, but that for practical reasons the application time ($T_s = 138$ min) has to be in full hours.
Run Mode 4 with $T_s = 120$ min. The input and output parameters of this run are presented in Column 5 of Table 5. The final result can be summarized as follows.

If water at a fixed flow rate of 30 l/s is applied for two hours, a basin of 50 m long and 40 m wide can be irrigated with an application efficiency of 93%. In approximately the last quarter of the basin (13 m), the required depth of 100 mm is not reached, causing an average under-irrigation of about 8 mm. The storage efficiency over the whole basin is 98%.

Table 5. Overview of input and output parameters in Problem 1

Input parameters	Mode 1	Mode 3	Mode 3	Mode 4
1	2	3	4	5
Number of sections	-	10	10	10
Constant inflow rate	30	30	30	30
Application time	-	-	-	120
Required depth	100	100	100	100
Maximum length-width ratio	2	-	-	-
Basin length	-	60	50	50
Basin width	-	40	40	40
Flow resistance	.20	.20	.20	.20
Infiltration parameter A	.72	.72	.72	.72
Infiltration parameter k	.14	.14	.14	.14
Output parameters	**Mode 1**	**Mode 3**	**Mode 3**	**Mode 4**
Basin length	57	-	-	-
Basin width	28	-	-	-
Minimum infiltration depth	-	-	-	82
Maximum infiltration depth	130	153	137	122
Average applied depth	119	135	124	108
Over-irrigation (37 m)	-	-	-	14
Under-irrigation (13 m)	-	-	-	8
Application efficiency	84	74	81	93
Storage efficiency	-	-	-	98
Application time	105	180	138	-
Advance time	67	124	85	85
Recession time	220	277	238	202

Problem 2

Given:
The infiltration capacity of a soil is characterized by k = 0.11 and A = 0.65, and the flow resistance of the basin is n = 0.15.

The required depth of infiltration is D_{req} = 100 mm and the basin dimensions are L = 100 m and B = 80 m.

Question:
What should be the required flow rate (Q)?

Table 6. Overview of input and output parameters in Problem 2

Input parameters	Mode 2	Mode 3	Mode 4
1	2	3	4
Number of sections	-	10	10
Constant inflow rate	-	70	70
Application time	-	-	180
Required depth	100	100	100
Basin length	100	100	100
Basin width	80	80	80
Flow resistance	.15	.15	.15
Infiltration parameter (A)	.65	.65	.65
Infiltration parameter (k)	.11	.11	.11
Output parameters	**Mode 2**	**Mode 3**	**Mode 4**
Constant inflow rate	40	-	-
Minimum infiltrated depth	-	-	87
Maximum infiltrated depth	122	112	100
Average applied depth	114	107	95
Over-irrigation (0 m)	-	-	0
Under-irrigation (100 m)	-	-	5
Application efficiency	88	93	-[1]
Storage efficiency	-	-	95
Application time	379	204	-
Advance time	209	112	112
Recession time	803	706	590

[1] The value of the application efficiency is not given because the average applied depth is less than the required depth

Solution:
Start in Mode 2. The input and output parameters of this run are presented in Column 2 of Table 6.

The required flow rate is Q = 40 l/s, the application time is T_s = 379 min. Let us suppose that this application time is too long. Continue in Mode 3 and specify, for instance, a higher flow rate Q = 70 l/s. The input and output parameters of this run are presented in Column 3 of Table 6.

Let us suppose that these results are acceptable, but that for practical reasons the application time (T_s = 204 min) must be in full hours. Run Mode 4 with T_s = 180 min. The input and output parameters of this run are presented in Column 4 of Table 6. The final result can be summarized as follows.

A basin with fixed dimensions of 100 x 80 m^2 can be irrigated in three hours at a flow rate of 70 l/s. Over the whole length of the basin, the required depth of 100 mm is not reached, resulting in an average under-irrigation of about 5 mm and yielding a storage efficiency of 95%.

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List of symbols

A	infiltration exponent Kostiakov equation (–)
B	basin width (m)
D	infiltrated depth (mm)
D_{av}	average infiltrated depth (mm)
D_{max}	maximum infiltrated depth (mm)
D_{min}	minimum infiltrated depth (mm)
D_{req}	required depth of water to be stored (mm)
D_s	average depth of water actually stored in a soil layer which can store the required depth (mm)
E_a	application efficiency (%)
E_s	storage efficiency (%)
k	infiltration constant in Kostiakov equation (mm/s^A)
L	basin length (m)
n	flow resistance
Q	constant inflow rate (l/s)
T	infiltration opportunity time (s)
T_s	application time (min)

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ISBN 90 70754 12 6